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AERODYNAMIC CHARACTERISTICS OF THE HL-10 MANNED LIFTING ENTRY VEHICLE AT MACH 0.95 TO 1.20

by Charles D. Harris

Langley Research Center

Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1968

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AERODYNAMIC CHARACTERISTICS OF THE HL-10 MANNED LIFTING ENTRY VEHICLE AT MACH 0.95 TO 1.20*

By Charles D. Harris
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SUMMARY

An investigation was made in the Langley 8-foot transonic pressure tunnel to determine the static longitudinal and lateral stability and control characteristics of the transonic configuration of a manned lifting entry vehicle (HL-10). The investigation was made at Mach numbers of 0.95 to 1.20 and through an angle-of-attack range of approximately 0° to 25° at angles of sideslip of approximately 0° and 5°. The results include the effect on the aerodynamic characteristics of uniform and differential elevon deflections.

The vehicle with elevons undeflected trimmed at near maximum lift-drag ratios. Uniform negative elevon deflection or elevons differentially deflected resulted in pitch-up at angles of attack of about 20° at a Mach number of 0.95. The vehicle exhibited directional stability and positive effective dihedral. Roll-control effectiveness was positive for all test conditions and was accompanied by favorable yaw due to roll except at a Mach number of 1.20 for angles of attack greater than about 20°.

INTRODUCTION

Studies of the aerodynamic characteristics of a manned entry vehicle contoured to provide some lift and thus some maneuvering and conventional landing capability have been made by the National Aeronautics and Space Administration, Langley Research Center. The vehicle, having a 74° swept-delta planform, a blunt nose, and extensive boattailing, has been designated "the basic HL-10 (horizontal lander 10)." Variations in body and fin contouring and numerous center and outboard vertical-tail arrangements have been investigated in various configurations to establish a configuration acceptable at all operational Mach numbers. A summary of results for several configurations tested at Mach numbers from low subsonic to hypersonic speeds is given in reference 1.

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*Title, Unclassified.

Simple flaps on the fins and on the elevons which have different deflection angles for the various operational speed ranges improved both the subsonic maximum trimmed lift-drag ratio and the transonic longitudinal stability characteristics of the vehicle. (See ref. 1.) These flaps were positioned for the transonic-speed range of the present investigation, and the complete configuration was designated "the transonic configuration."

The results presented herein include the effect on the aerodynamic characteristics of elevons uniformly deflected for pitch control and differentially deflected for roll control. Directional and lateral stability characteristics of the model with elevons undeflected at sideslip angles of approximately 0° and 5° are also presented. The investigation was made at Mach numbers of 0.95 to 1.20 and through an angle-of-attack range of approximately 0° to 25°.

This transonic configuration has been investigated at high subsonic and supersonic speeds, and the results are presented in references 2 and 3, respectively. Data have also been obtained with various canopy shapes in a range of Mach numbers from low subsonic to hypersonic speeds and are reported in reference 4.

SYMBOLS

The lift and drag data are referenced to the stability axes, the rolling moment and yawing moment are referenced to the body axes, and the side-force and pitching-moment data are referenced to the common lateral axis of the stability and body axes. The origin of the stability and body axes is the moment-reference point located 53 percent of the body length behind the vehicle nose and 1.25 percent of the body length below the reference center line. All coefficients are based on the total projected planform area (tip fins excluded), the span, and the length of the model.

The units used for the physical quantities in this paper are given both in the International System of Units (SI) and in the U.S. Customary Units. Factors relating the two systems are given in reference 5.

b — span of body without tip fins (model value, 26.19 cm (10.31 in.))

C_A — axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_D — drag coefficient, $\frac{\text{Drag force}}{qS}$

C_L — lift coefficient, $\frac{\text{Lift force}}{qS}$

C_l — rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$

$C_{l_\beta} = \dfrac{\Delta C_l}{\Delta \beta}$ per degree

C_m	pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qSl}$
C_N	normal-force coefficient, $\dfrac{\text{Normal force}}{qS}$
C_n	yawing-moment coefficient, $\dfrac{\text{Yawing moment}}{qSb}$

$C_{n_\beta} = \dfrac{\Delta C_n}{\Delta \beta}$ per degree

C_Y	side-force coefficient, $\dfrac{\text{Side force}}{qS}$

$C_{Y_\beta} = \dfrac{\Delta C_Y}{\Delta \beta}$ per degree

L/D	lift-drag ratio, C_L/C_D
l	body length (model value, 40.64 cm (16.00 in.))
M	free-stream Mach number
q	free-stream dynamic pressure, N/m^2 (lbf/ft^2)
R	Reynolds number based on model length l
S	body projected planform area (model value, 589 cm^2 (0.6344 ft^2))
α	angle of attack measured relative to reference line of model, deg
β	angle of sideslip, deg
δ_a	differential roll-control deflection (equal to right elevon deflection angle minus left elevon deflection angle), deg
δ_e	elevon deflection angle measured in plane perpendicular to hinge line, positive when trailing edge is down, deg
δ_{ef}	elevon-flap deflection angle (angle between elevon flap and body upper surface in region of elevon), positive when trailing edge is above body surface at $\delta_e = 0^\circ$, deg

δ_{if} deflection angle of inner flap on tip fin (angle between flap and tip-fin inner surface measured normal to hinge line), positive when trailing edge moves toward body center line, deg

ϵ fin toe-in angle (angle between plane of symmetry of model and outer surface of fin, measured in horizontal reference plane of model), deg

ϕ fin roll-out angle (angle between plane of symmetry of model and outer surface of fin, measured in plane normal to fin roll axis), deg

APPARATUS AND TEST CONDITIONS

Tunnel and Instrumentation

The investigation was made in the Langley 8-foot transonic pressure tunnel. The test section of this tunnel is square in cross section with the upper and lower walls axially slotted to permit changing the test-section Mach number continuously from 0 to over 1.20 with negligible effects of choking and blockage. The total pressure of the tunnel air can be varied from a minimum value of about 0.25 atmosphere at all test Mach numbers to a maximum value of about 1.5 atmospheres at transonic Mach numbers and about 2.0 atmospheres at Mach numbers of 0.40 or less. The tunnel air is dried sufficiently to avoid condensation effects.

Aerodynamic forces and moments were measured with a six-component internal strain-gage balance supported by a conventional sting which was attached to the remotely operated tunnel central support system.

Model

Details of the HL-10 configuration with tip fins I_4 (with $\epsilon = 10.8^{o}$ and $\phi = 8.5^{o}$) and center vertical tail E_2 are presented in figure 1. Model-component designations I_4 and E_2 are consistent with those established for the HL-10 program. The model incorporates tip fin and elevon upper surface flaps to improve both the subsonic maximum trimmed lift-drag ratio and the transonic longitudinal stability characteristics of the vehicle. For the Mach number range of the present investigation, the trailing edge of the flaps on the inner surface of the tip fins was deflected toward the model center line $\left(\delta_{if} = 30^{o}\right)$ and the elevon upper surface flap was deflected upward $\left(\delta_{ef} = 20^{o}\right)$. The complete configuration was designated "the transonic configuration."

Photographs of a representative model showing the tip fin and elevon flaps in the transonic mode are presented in figure 2. Cross-sectional ordinates for the basic body alone are presented in reference 3, and cross-sectional views of the basic body with the I_4 tip fins are presented in reference 4.

Test Conditions

The test conditions for the present investigation are as follows:

M	q		R
	kN/m^2	lbf/ft^2	
0.95	13.55	283	2.04×10^6
1.00	14.17	296	2.07
1.10	14.46	302	2.00
1.20	13.36	279	1.78

All tests were made at angles of attack from approximately 0° to 25°. For the configuration with elevons undeflected the tests were made at angles of sideslip of approximately 0° and 5°; for the configuration with elevons deflected, the tests were made at an angle of sideslip of 0°.

The investigation included tests to determine the effect on the aerodynamic characteristics of the elevons uniformly deflected for pitch control and differentially deflected for roll control on the transonic configuration. Uniform elevon deflection from $\delta_e = -5^\circ$ to $\delta_e = 20^\circ$ and differential elevon deflections from $\delta_a = 0^\circ$ to $\delta_a = -30^\circ$ referenced to $\delta_e = 0^\circ$ were investigated. In all tests, 0.254-cm (0.10-inch) strips of No. 60 carborundum grit were used along the 12.5-percent-chord line, on the upper as well as the lower surface, and around the body 5.08 cm (2 inches) from the nose.

Accuracy

Maximum balance error, based on 0.5 percent of the maximum design load of each component and expressed in coefficient form, is estimated to be within the following limits:

C_N . . . . ±0.0120
C_A . . . . ±0.0028
C_m . . . . ±0.0011
C_n . . . . ±0.0006
C_l . . . . ±0.0002
C_Y . . . . ±0.0028

The angle of attack, which was corrected for deflection of the balance and sting support under aerodynamic load, is estimated to be accurate within $\pm 0.1^\circ$; and the average free-stream Mach number is accurate within ±0.005. The aerodynamic force and moment data presented herein are considered to be free of tunnel-boundary interference. Drag data are measured values and have not been corrected to free-stream conditions at the model base.

RESULTS AND DISCUSSION

The effects on the aerodynamic longitudinal performance and stability characteristics of elevons uniformly deflected for pitch control and differentially deflected about $\delta_e = 0^\circ$ for roll control at a sideslip angle of approximately 0° are presented in figures 3 and 4, respectively. Variation of uniform elevon deflection required for trim and the resulting lift coefficients and lift-drag ratios through the test angle-of-attack range, obtained from cross plots of figure 3, are presented in figure 5.

Figures 3 and 5 indicate that the model with elevons undeflected trimmed at near maximum lift-drag ratio. For $\delta_e = 0^\circ$, the pitching-moment-curve slope at trim conditions generally increased with Mach number through 1.10, with a small reduction as the Mach number was further increased to 1.20. Uniform deflection of the elevons in the positive direction generally resulted in slightly increased pitching-moment-curve slopes near trim and provided trim capability over a large portion of the angle-of-attack range. Uniform negative elevon deflection (fig. 3(a)) or elevons differentially deflected about $\delta_e = 0^\circ$, in which one elevon was deflected negatively (fig. 4(a)), resulted in pitch-up at angles of attack of about 20° for a Mach number of 0.95. Differential deflection of the elevons about $\delta_e = 0^\circ$ had little effect on the trim angle of attack for test Mach numbers other than 0.95 (fig. 4). There was, however, a small reduction in the trimmed lift-drag ratio.

The effect of sideslip on the basic lateral characteristics of the model with elevons undeflected is presented in figure 6 and the results are summarized in figure 7. The directional and lateral stability derivatives, shown in figure 7, are the average slopes between sideslip angles of approximately 0° and 5°.

The transonic configuration exhibited directional stability $\left(\text{positive values of } C_{n_\beta}\right)$ which decreased rapidly with increasing angle of attack. The configuration also exhibited positive effective dihedral $\left(\text{negative values of } C_{l_\beta}\right)$ for all test conditions. The decrease in the magnitude of the static directional derivative C_{n_β} with increase in angle of attack is probably due to the shielding effect of the body on the center vertical tail.

The effect on the directional and lateral characteristics of elevons differentially deflected about $\delta_e = 0^\circ$ is presented in figure 8. Roll-control effectiveness was positive for all test conditions and was accompanied by favorable yaw due to roll except at a Mach number of 1.20 for angles of attack greater than about 20°. There are, however, small reductions in the yawing-moment coefficients between differential elevon deflections of -20° and -30° at low angles of attack in some instances.

CONCLUSIONS

An investigation to determine the static longitudinal and lateral stability and control characteristics of the transonic configuration of a manned lifting entry vehicle was made in the Langley 8-foot transonic pressure tunnel. The investigation was made at Mach numbers of 0.95 to 1.20 and through an angle-of-attack range of approximately 0° to 25° at angles of sideslip of approximately 0° and 5°. The results include the effect on the aerodynamic characteristics of uniform and differential elevon deflections. The following conclusions are indicated:

1. The vehicle with elevons undeflected trimmed at near maximum lift-drag ratios.

2. Uniform negative elevon deflection or elevons differentially deflected resulted in pitch-up at angles of attack of about 20° for a Mach number of 0.95.

3. The vehicle exhibited directional stability which decreased rapidly with increasing angle of attack. The configuration also exhibited positive effective dihedral for all test conditions.

4. Roll-control effectiveness was positive for all test conditions and was accompanied by favorable yaw due to roll except at a Mach number of 1.20 for angles of attack greater than about 20°.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 21, 1967,
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1. Rainey, Robert W.: Summary of an Advanced Manned Lifting Entry Vehicle Study. NASA TM X-1159, 1965.

2. Henderson, William P.: Static Stability Characteristics of a Manned Lifting Entry Vehicle at High Subsonic Speeds. NASA TM X-1349, 1967.

3. Campbell, James F.; and Grow, Josephine W.: Stability and Control Characteristics of a Manned Lifting Entry Vehicle at Mach Numbers From 1.50 to 2.16 Including Hinge Moment and Pressure Distribution Data. NASA TM X-1314, 1966.

4. Ladson, Charles L.: Effects of Various Canopies on the Aerodynamic Characteristics of a Manned Lifting Entry Vehicle at Mach 0.06 to 6.8. NASA TM X-1321, 1966.

5. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors. NASA SP-7012, 1964.

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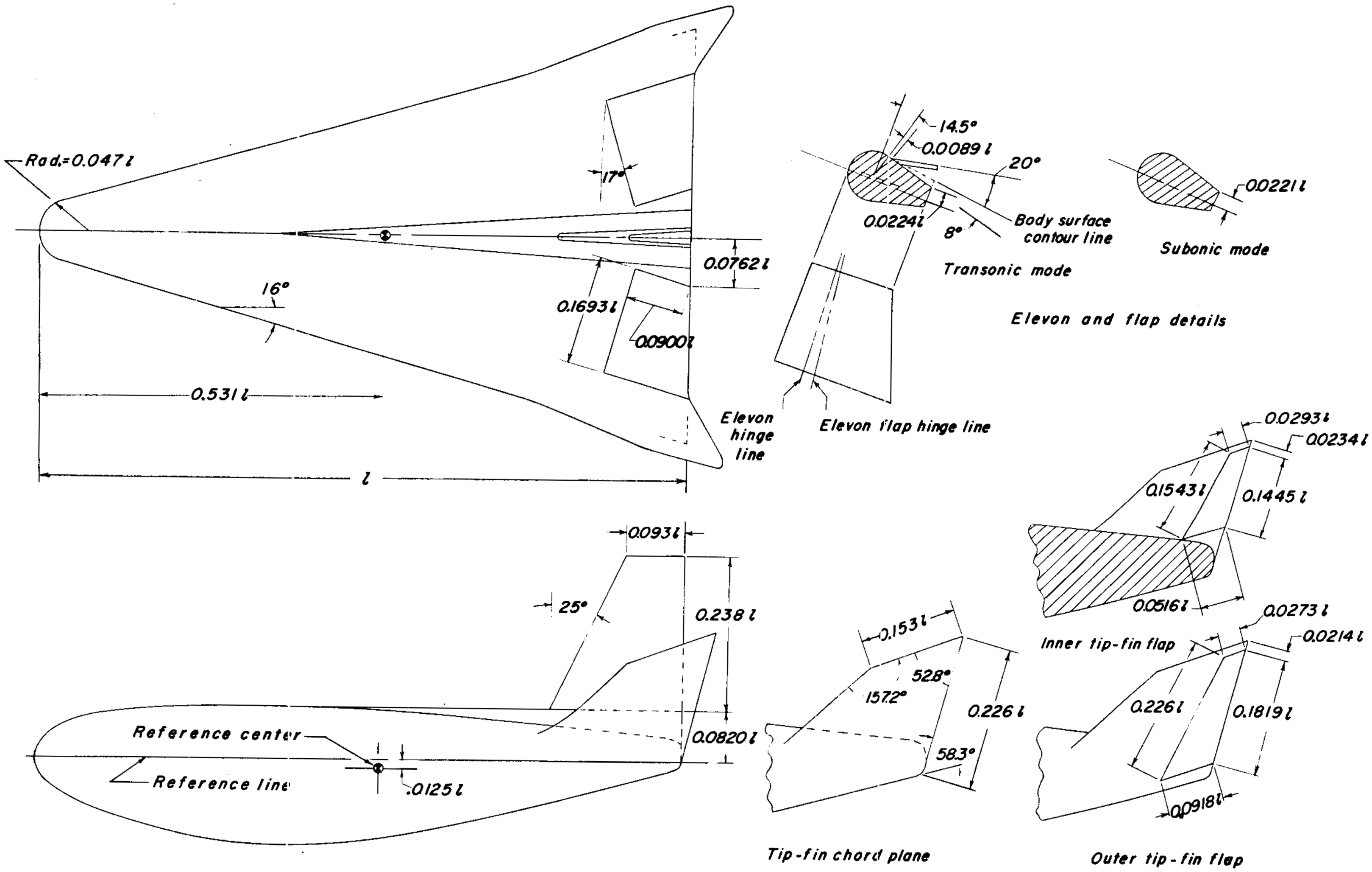

Figure 1.- Geometric characteristics of HL-10.

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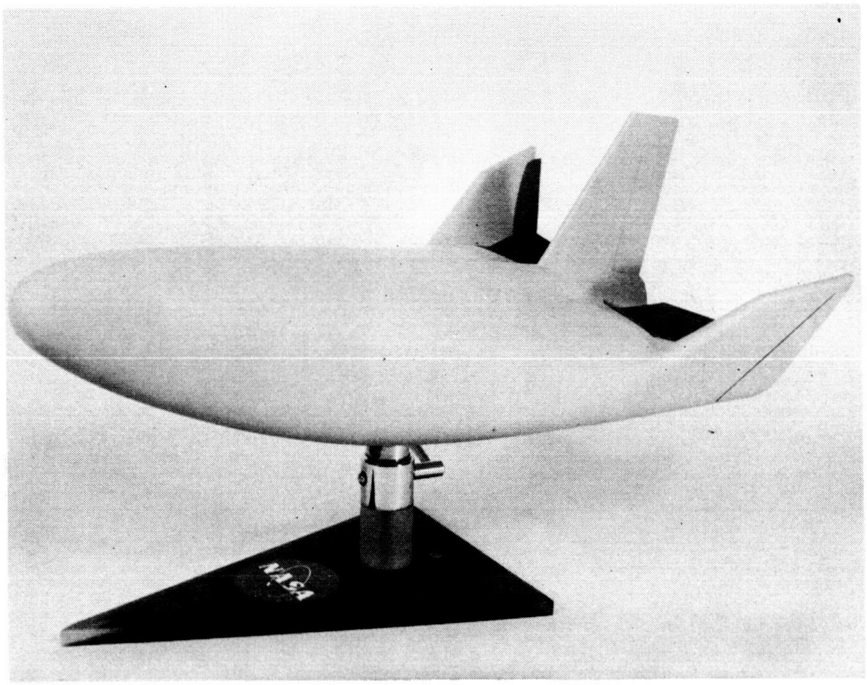

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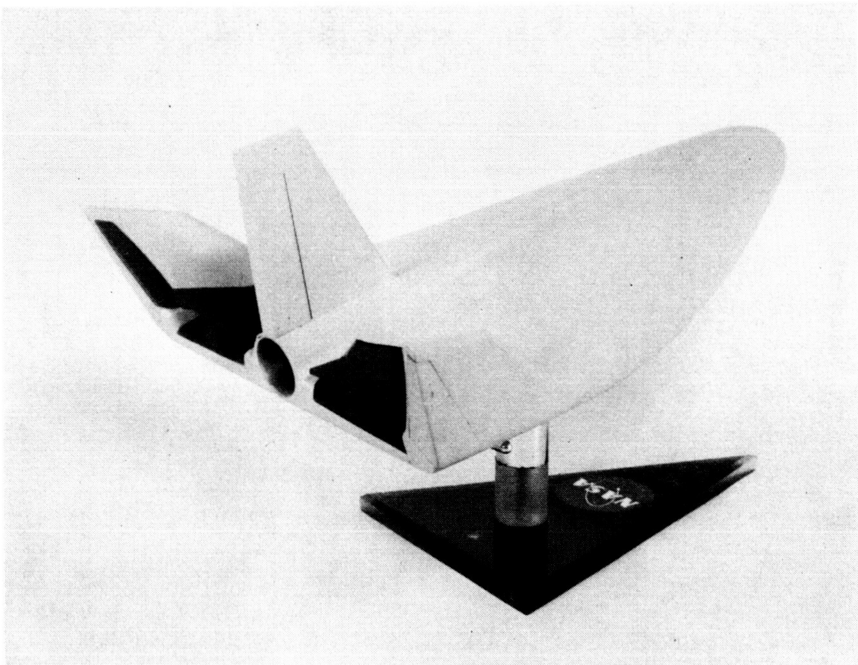
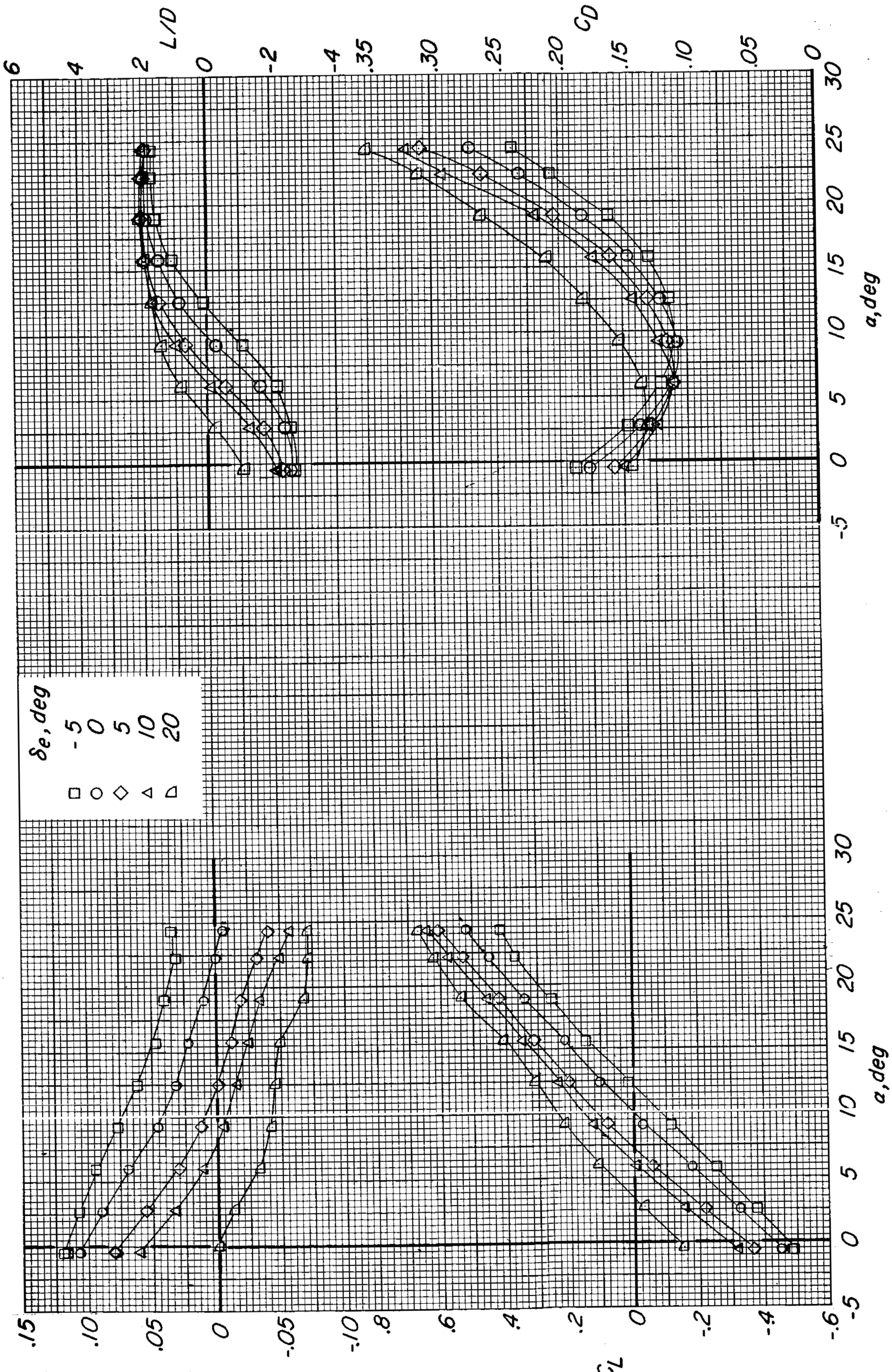


Figure 2.- Representative model of HL-10 in transonic mode. L-65-6176



(a) M = 0.95.

Figure 3.- Effect of uniform elevon deflection on longitudinal characteristics. $\beta \approx 0^{\circ}$.

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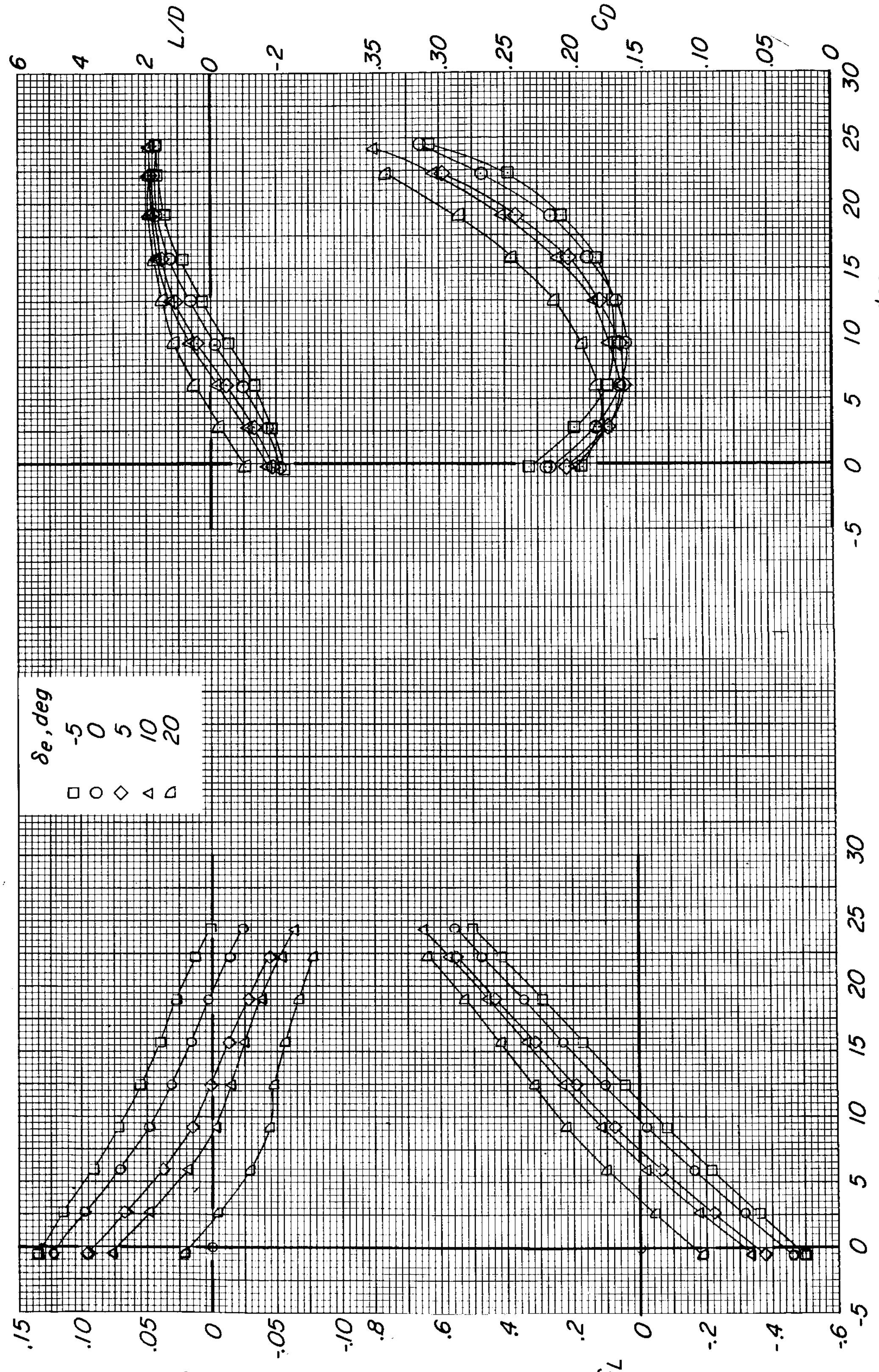

(b) M = 1.00.

Figure 3.- Continued.

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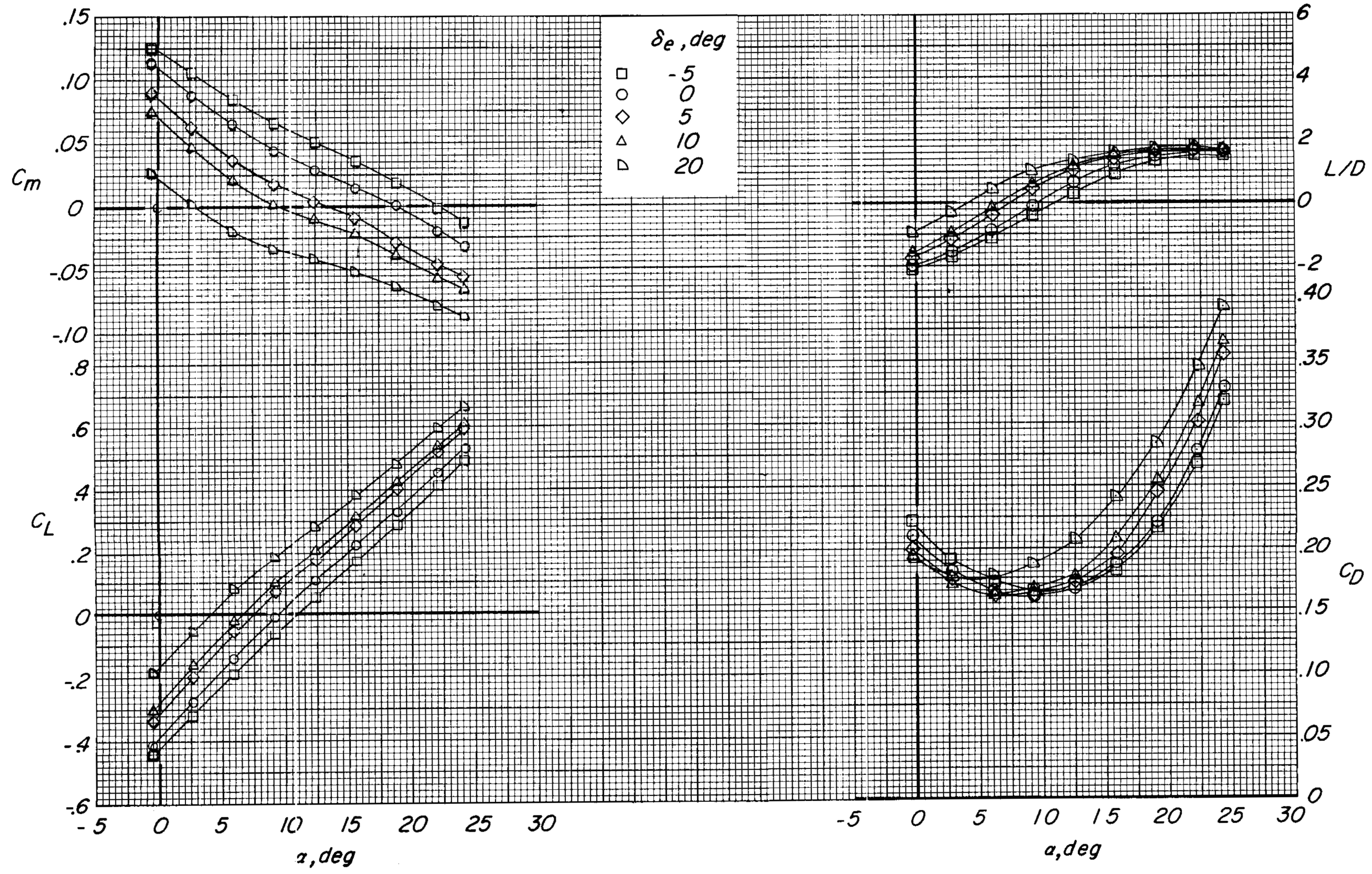
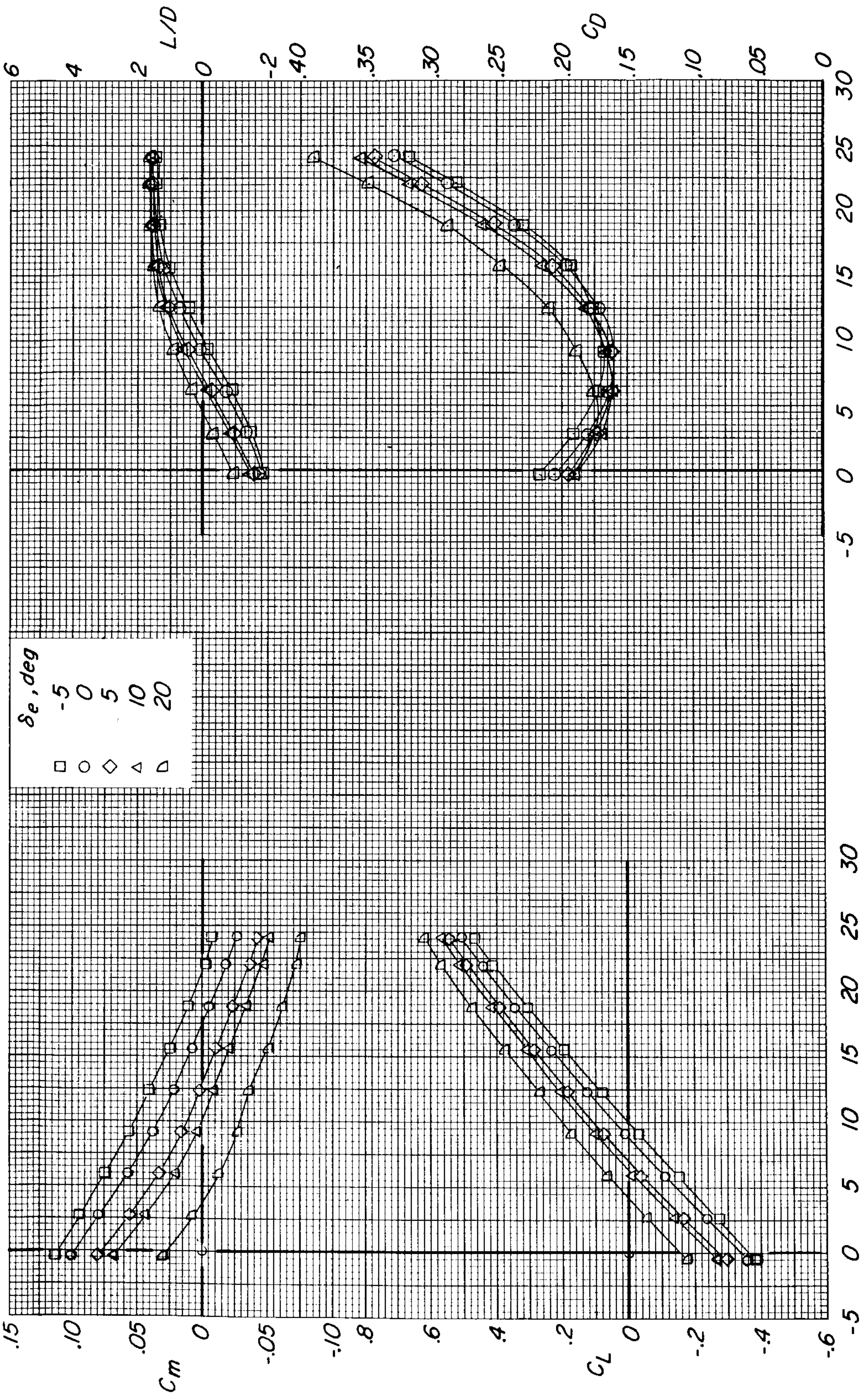


(c) M = 1.10.

Figure 3.- Continued.



(d) M = 1.20.

Figure 3.- Concluded.

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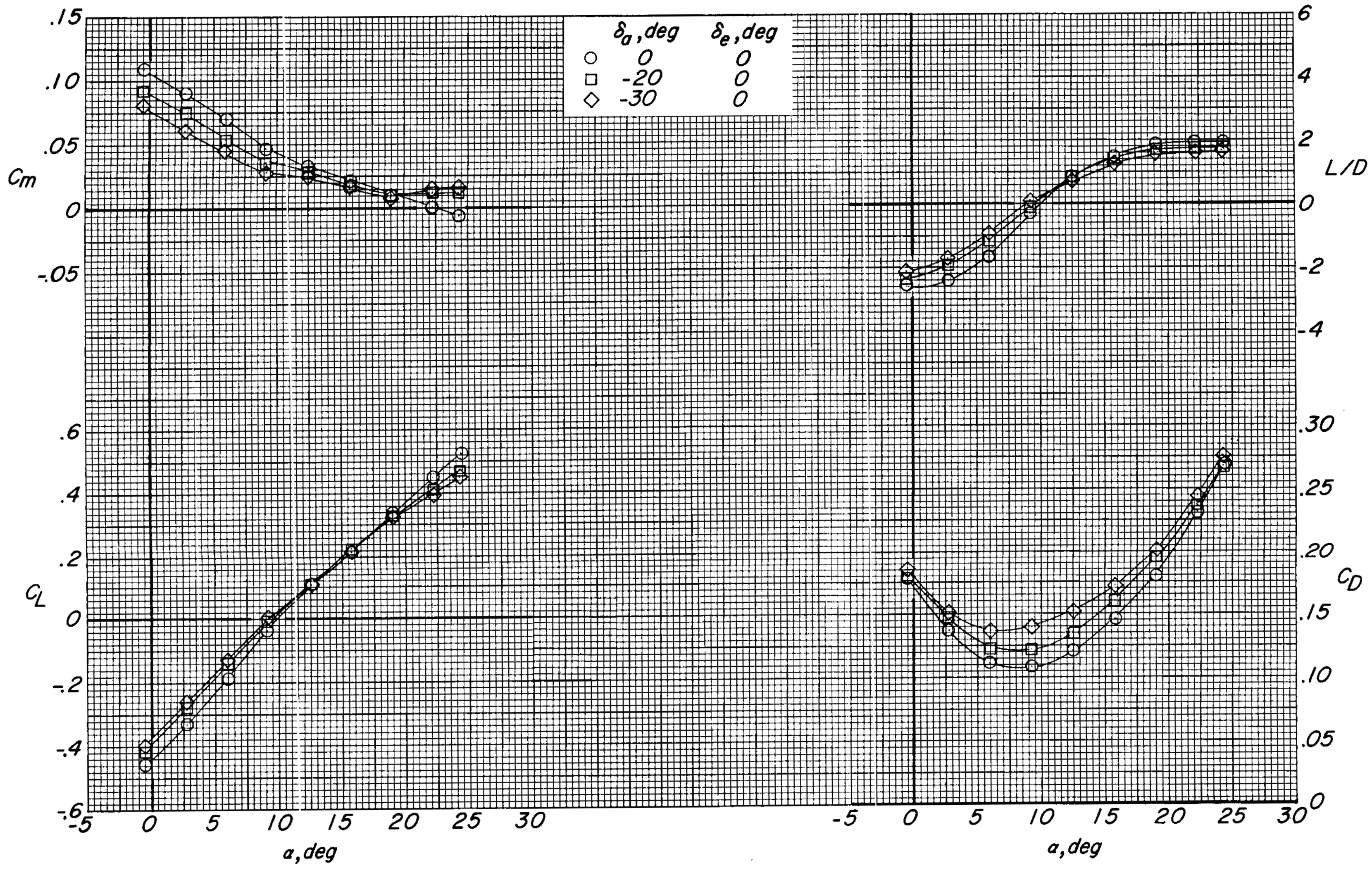

(a) M = 0.95.

Figure 4.- Effect of differential elevon deflection on longitudinal characteristics. $\beta \approx 0^0$.

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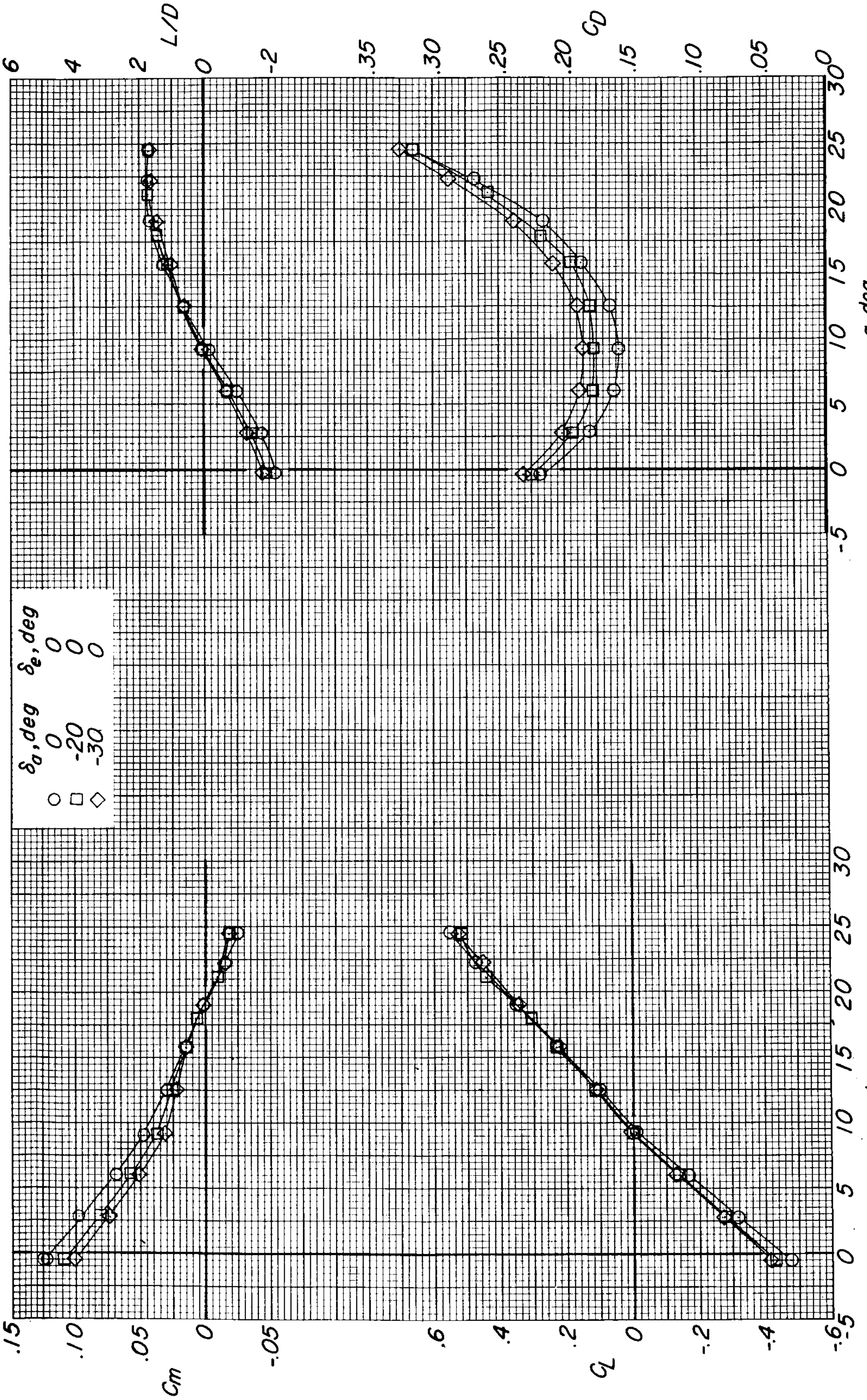
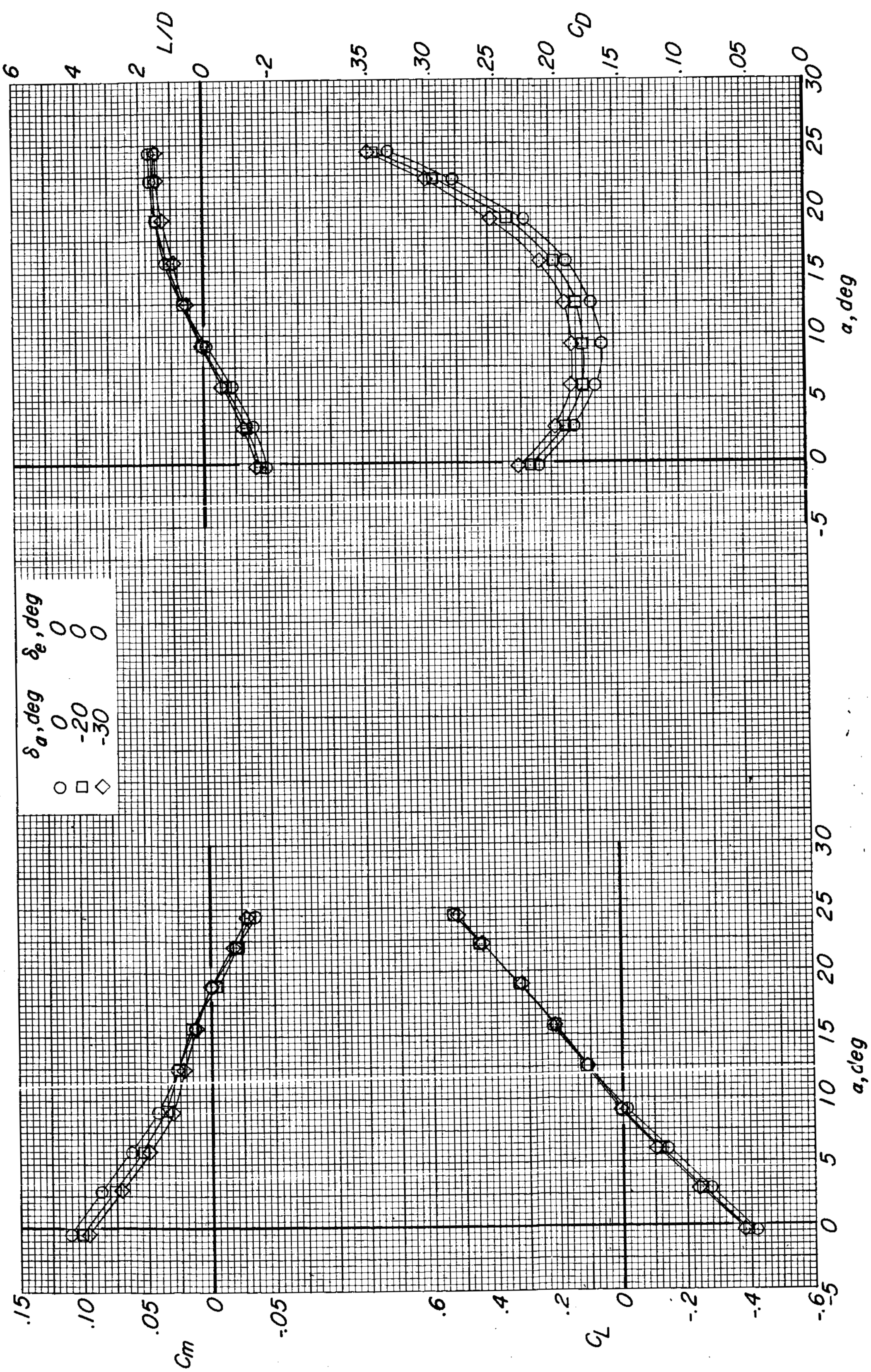


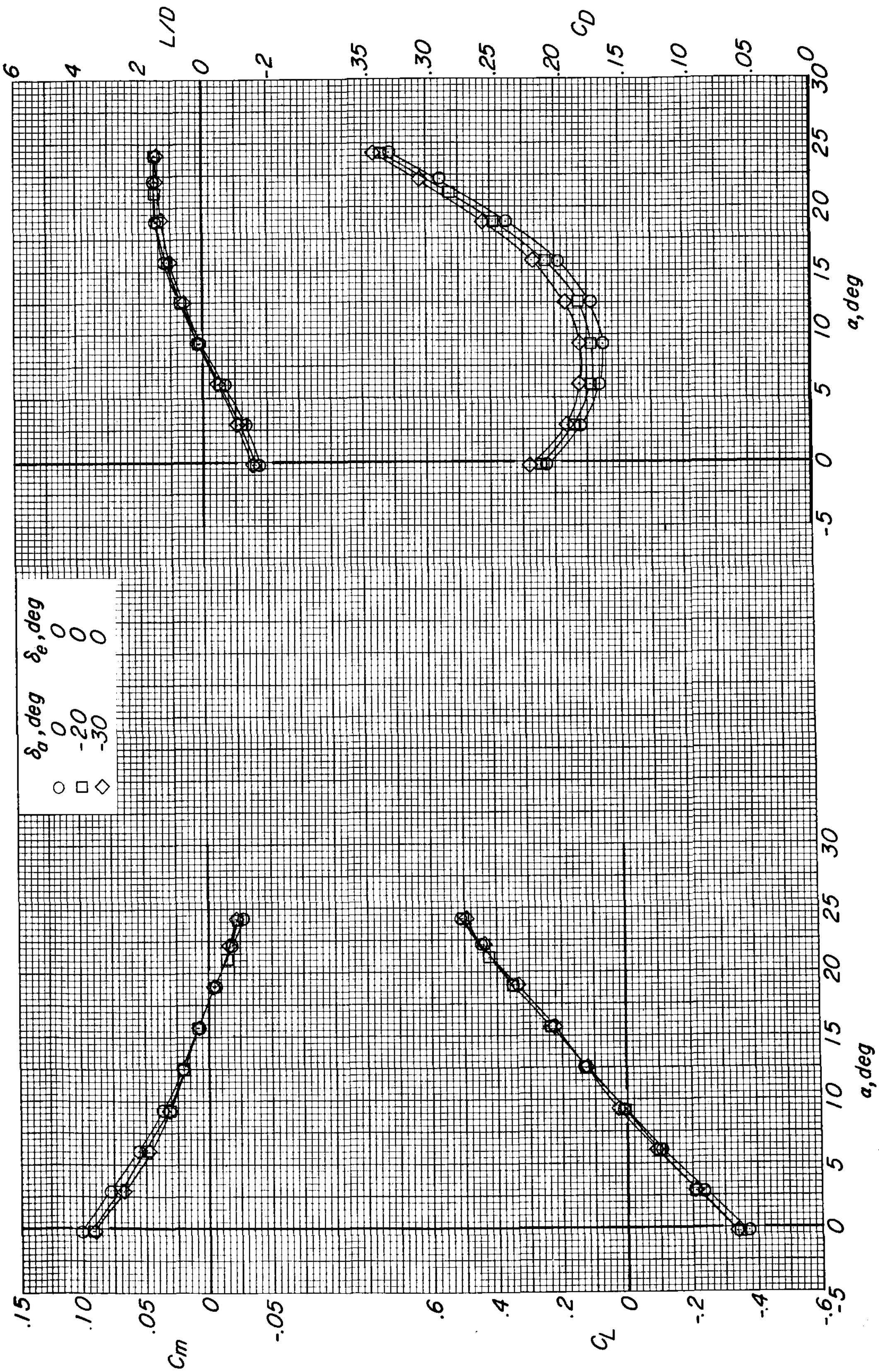
(b) M = 1.00.

Figure 4.- Continued.



(c) M = 1.10.

Figure 4.- Continued.



(d) M = 1.20.

Figure 4.- Concluded.

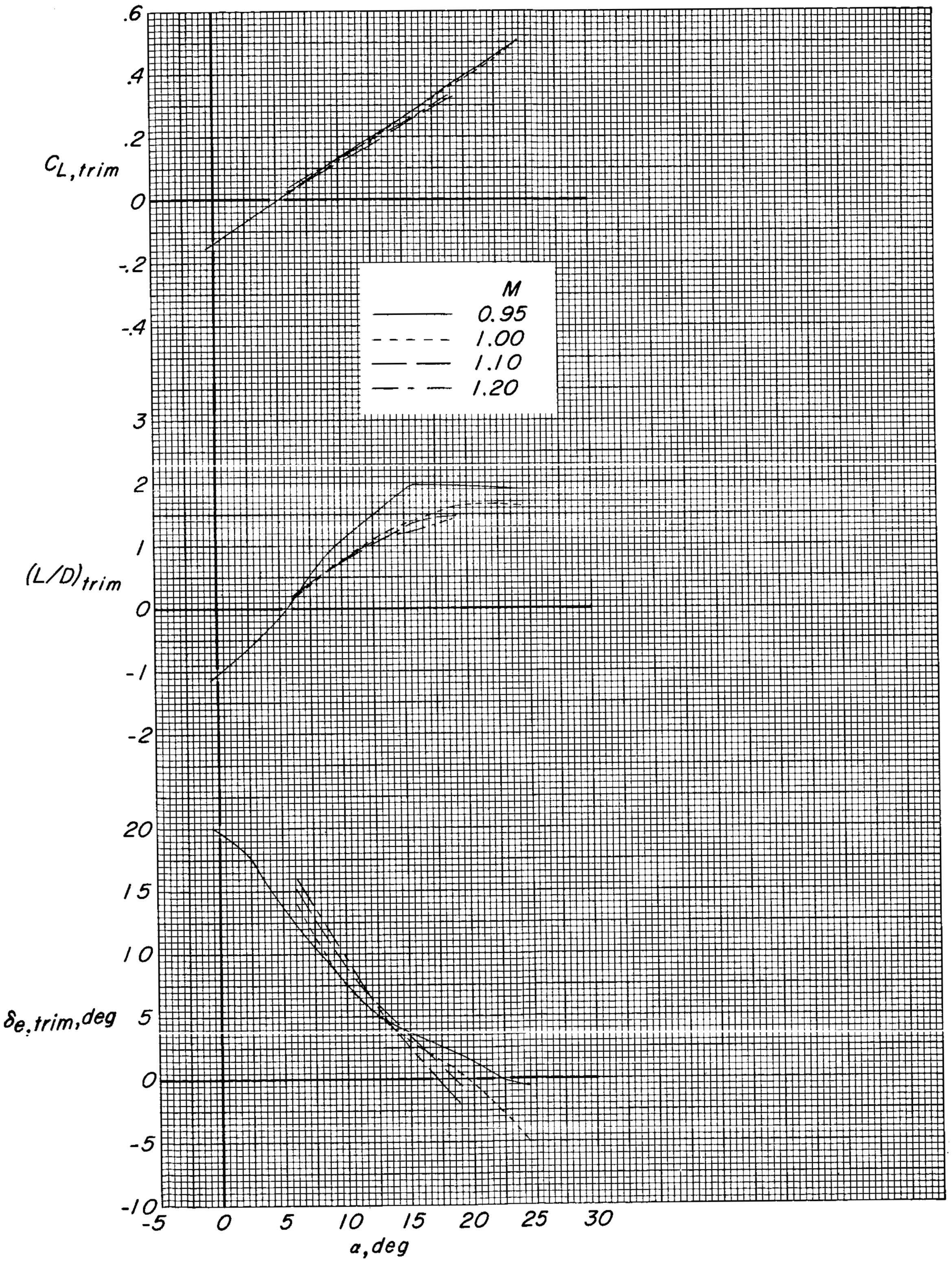
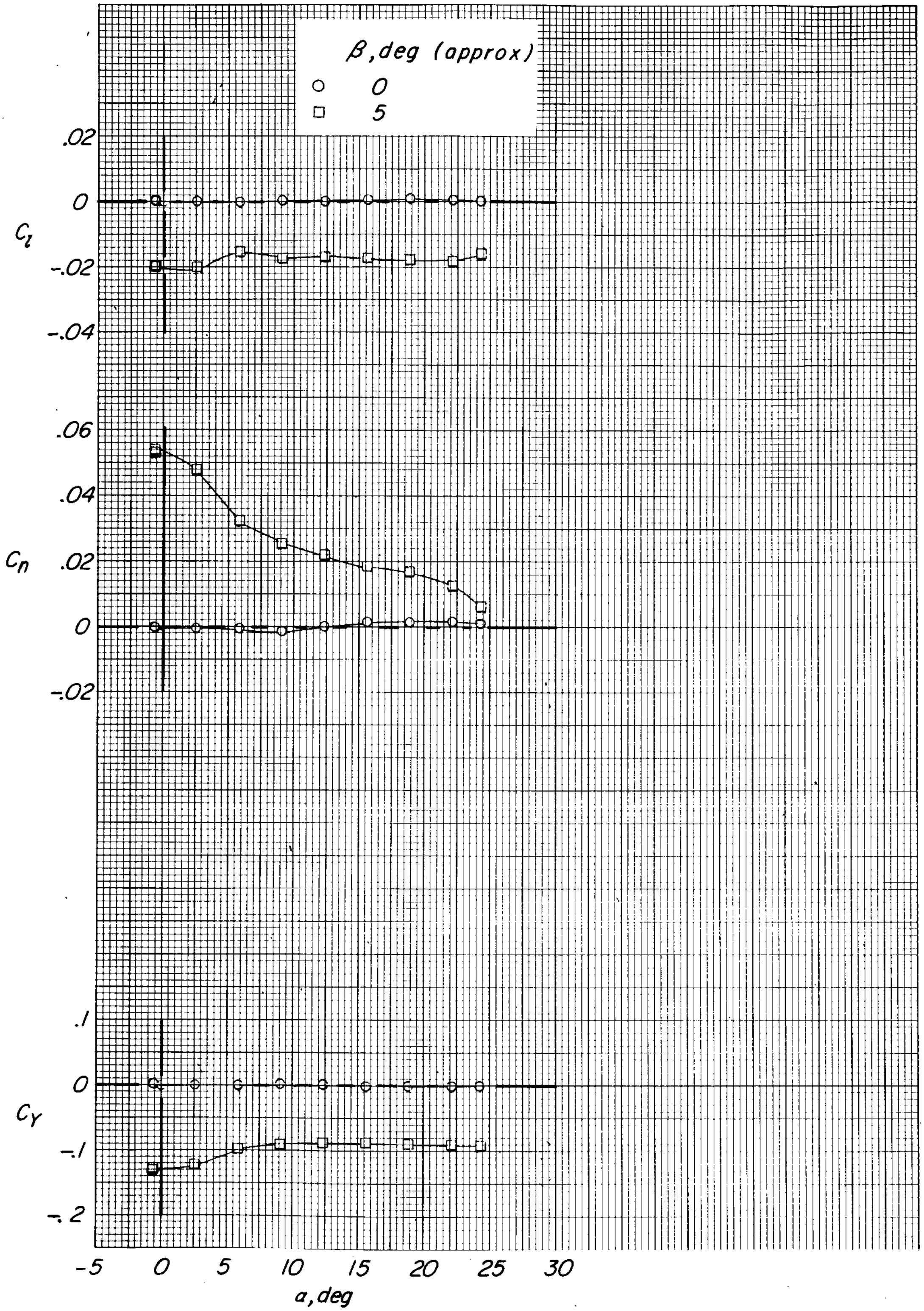
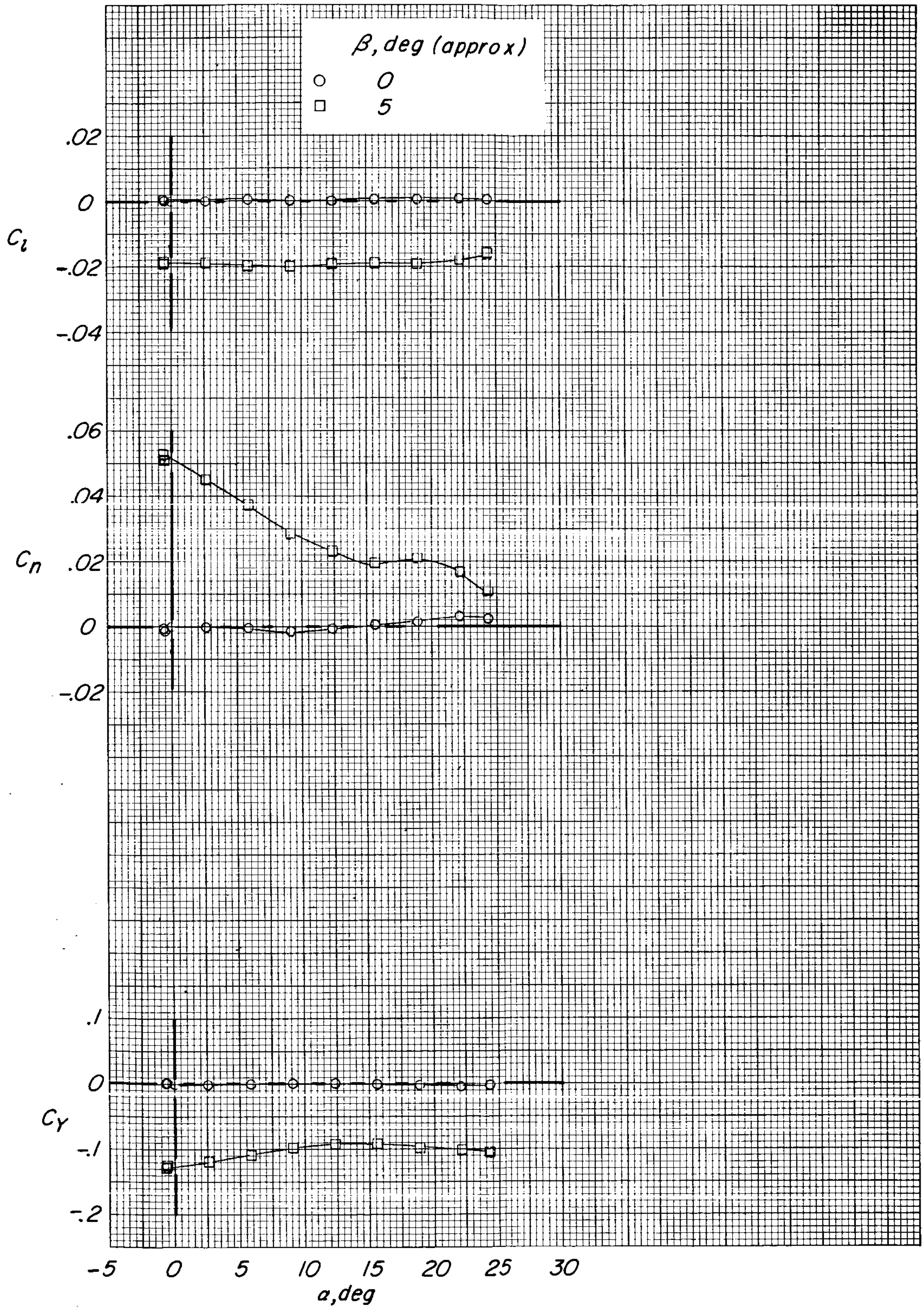


Figure 5.- Summary information on trimmed longitudinal characteristics.



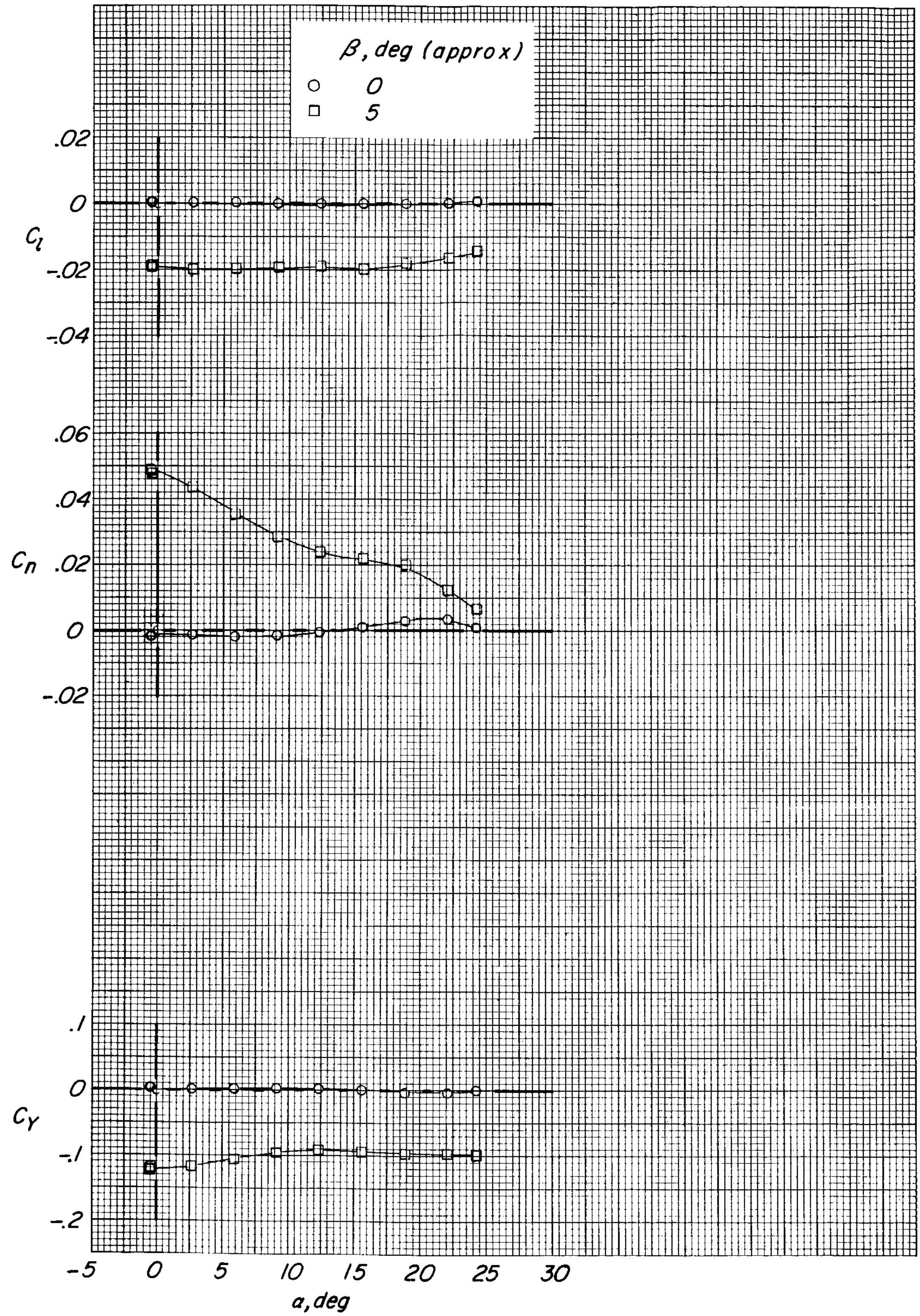
(a) M = 0.95.

Figure 6.- Effect of sideslip on lateral characteristics. $\delta_e = \delta_a = 0^0$.



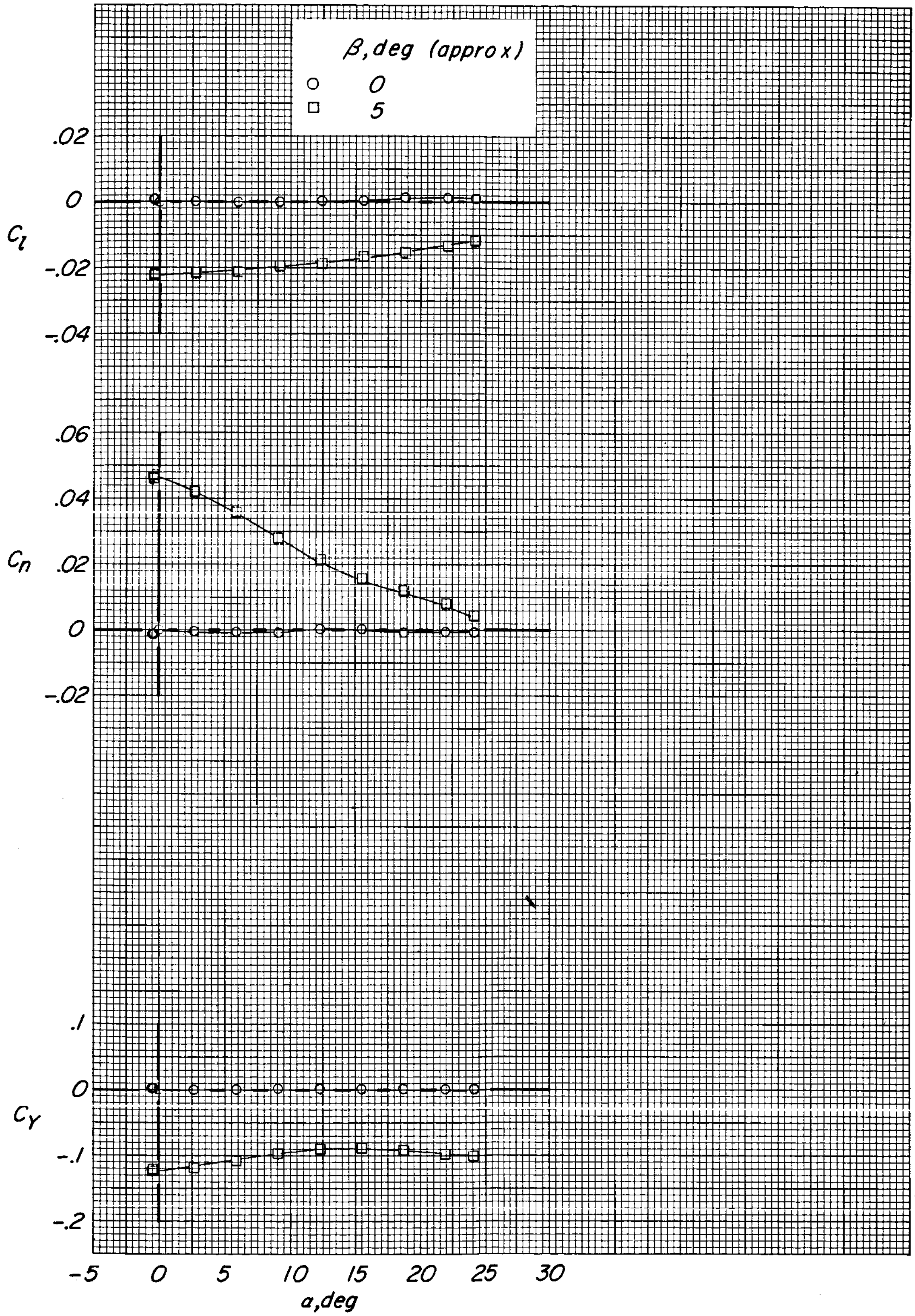
(b) M = 1.00.

Figure 6.- Continued.



(c) M = 1.10.

Figure 6.- Continued.



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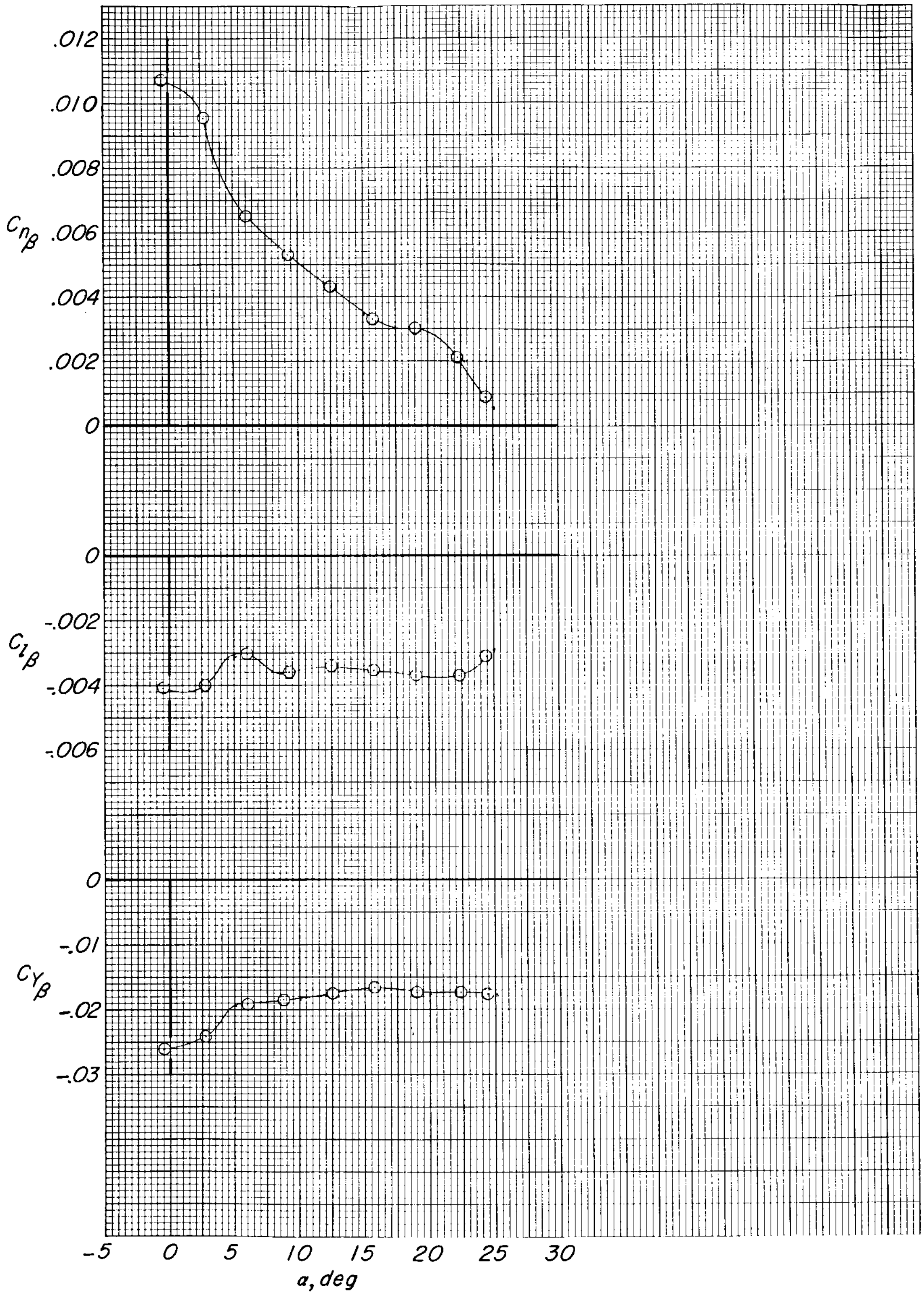
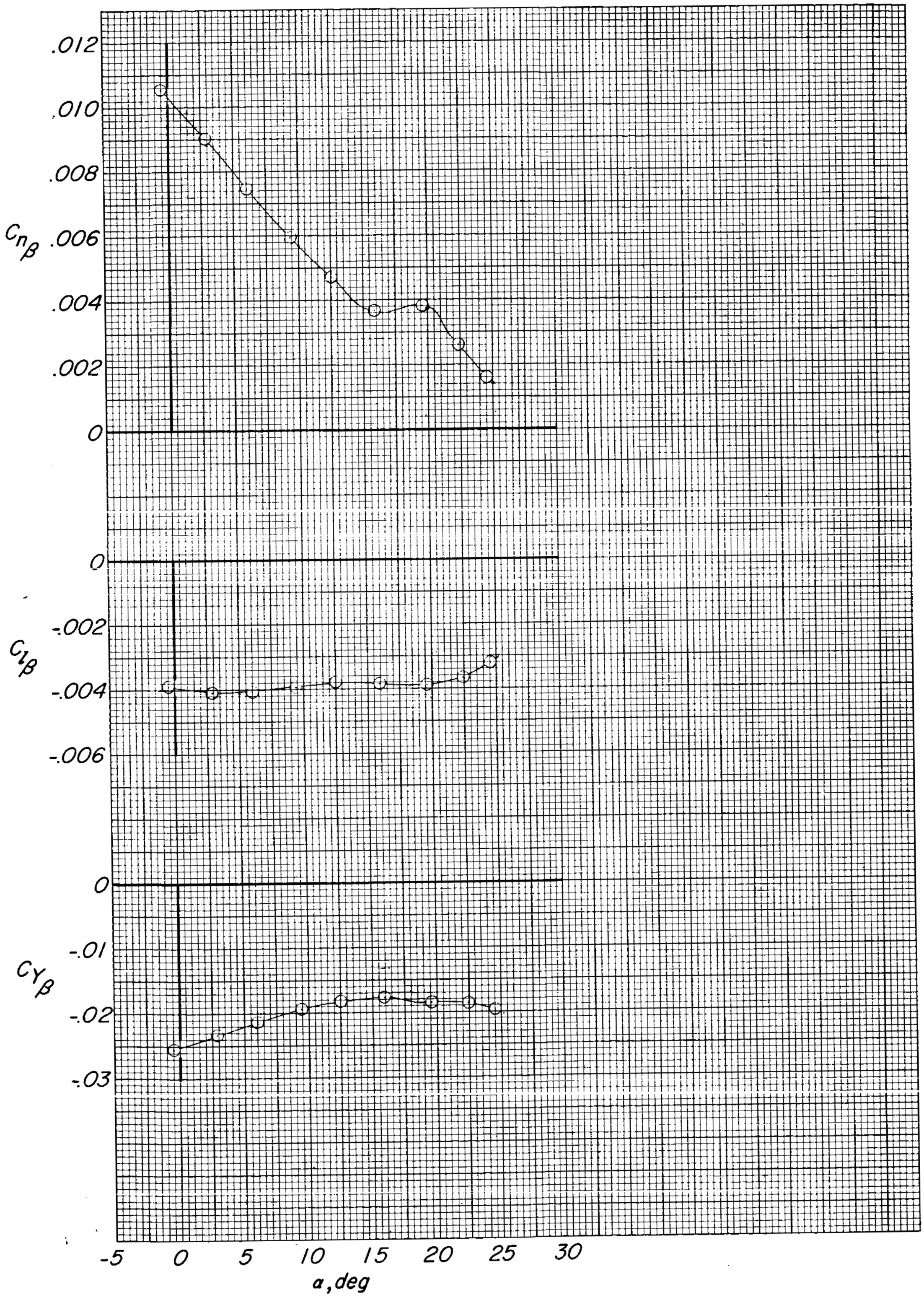


(a) M = 0.95.

Figure 7.- Summary of directional and lateral stability characteristics. $\delta_e = \delta_a = 0^0$.



(b) M = 1.00.

Figure 7.- Continued.

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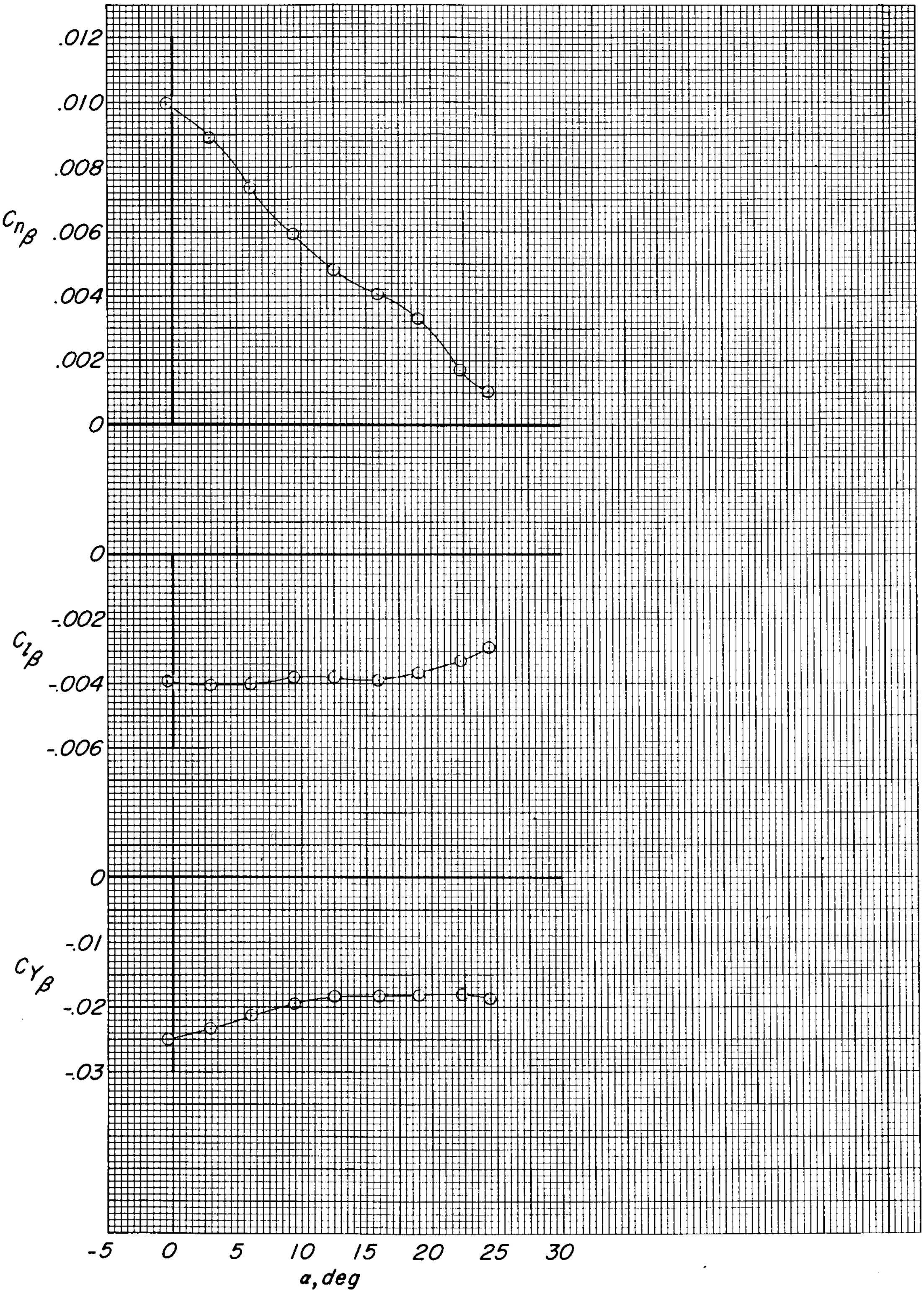

(c) M = 1.10.

Figure 7.- Continued.

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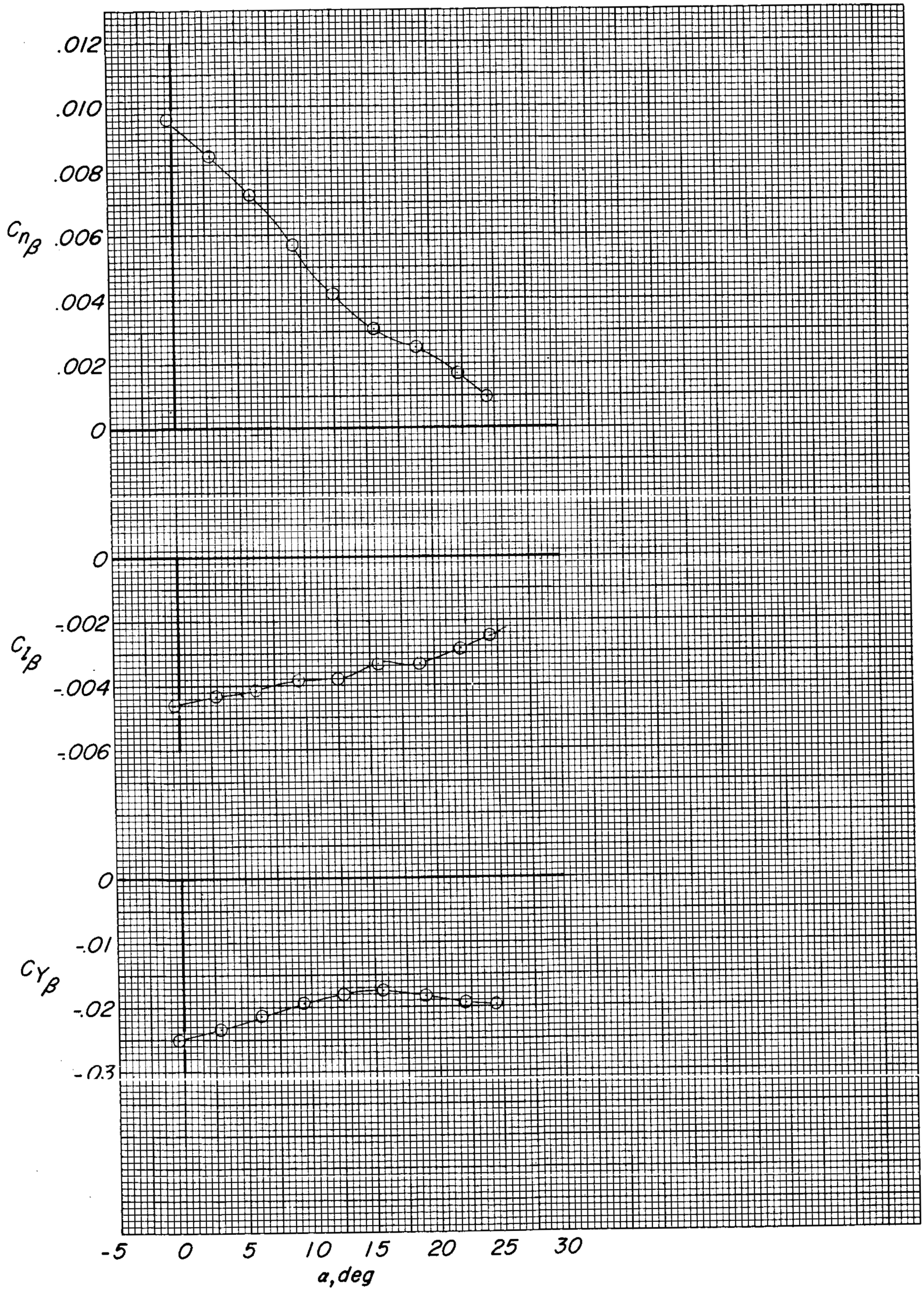

(d) M = 1.20.

Figure 7.- Concluded.

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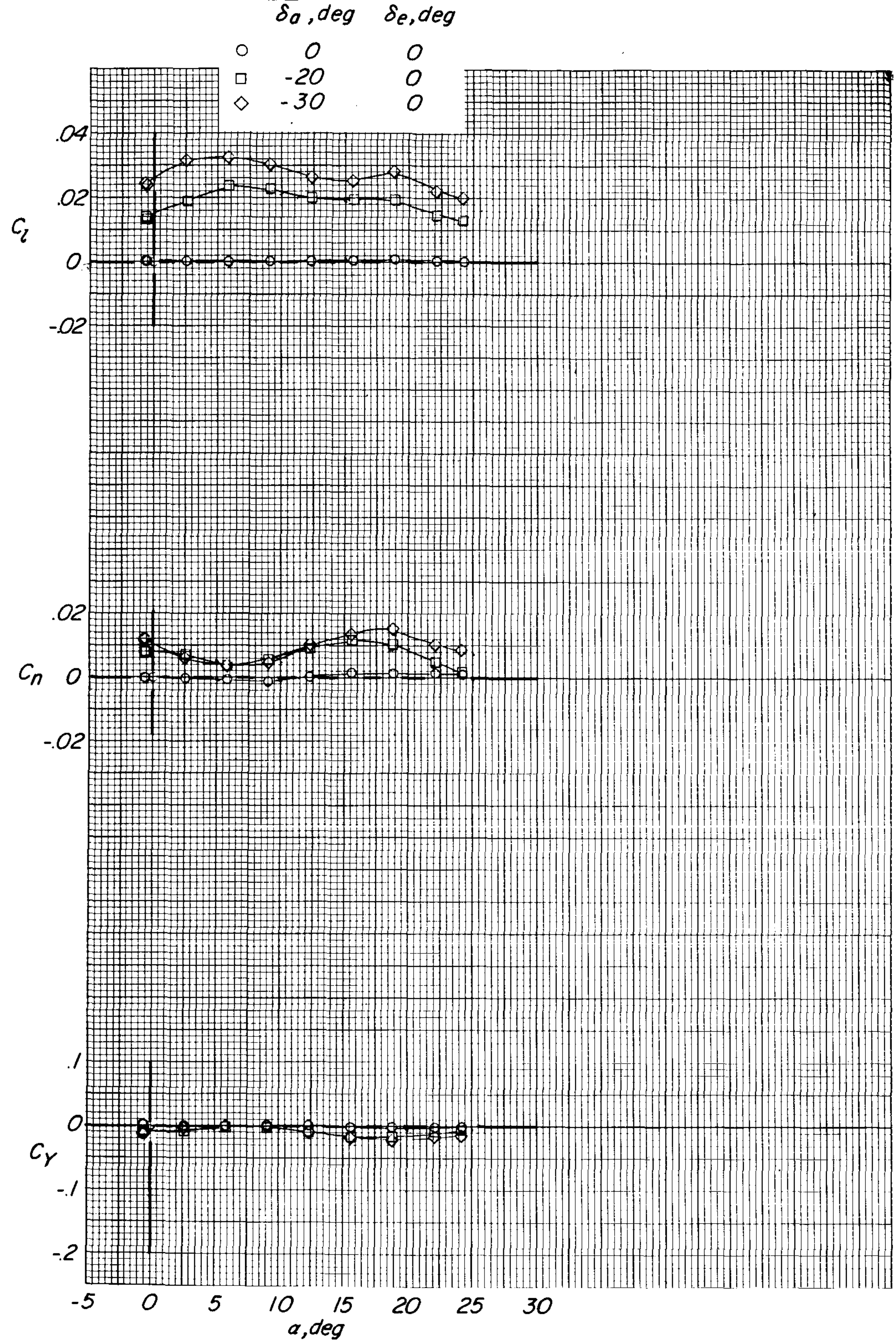

(a) M = 0.95.

Figure 8.- Effect of differential elevon deflection on lateral characteristics.

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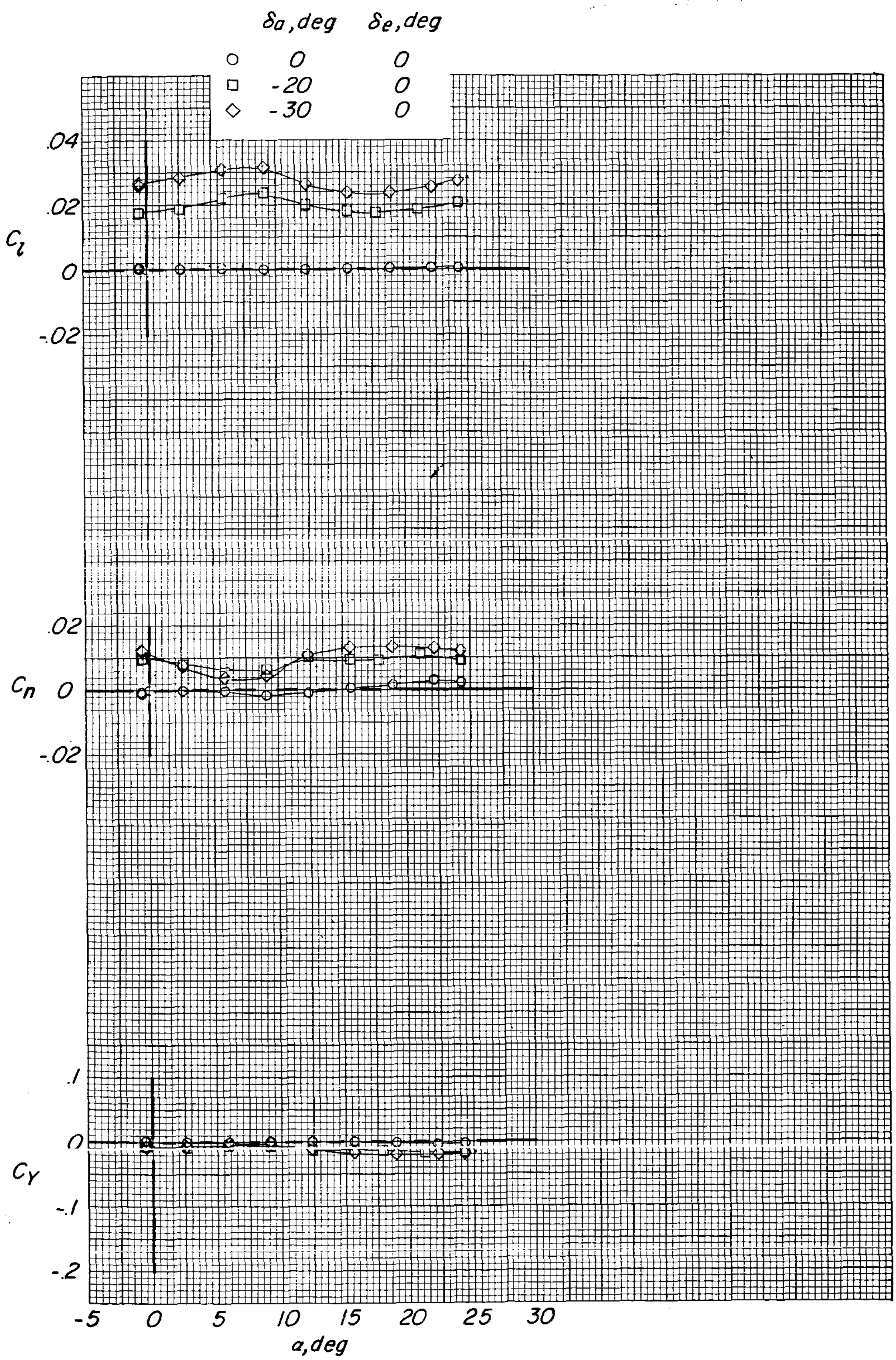

(b) M = 1.00.

Figure 8.- Continued.

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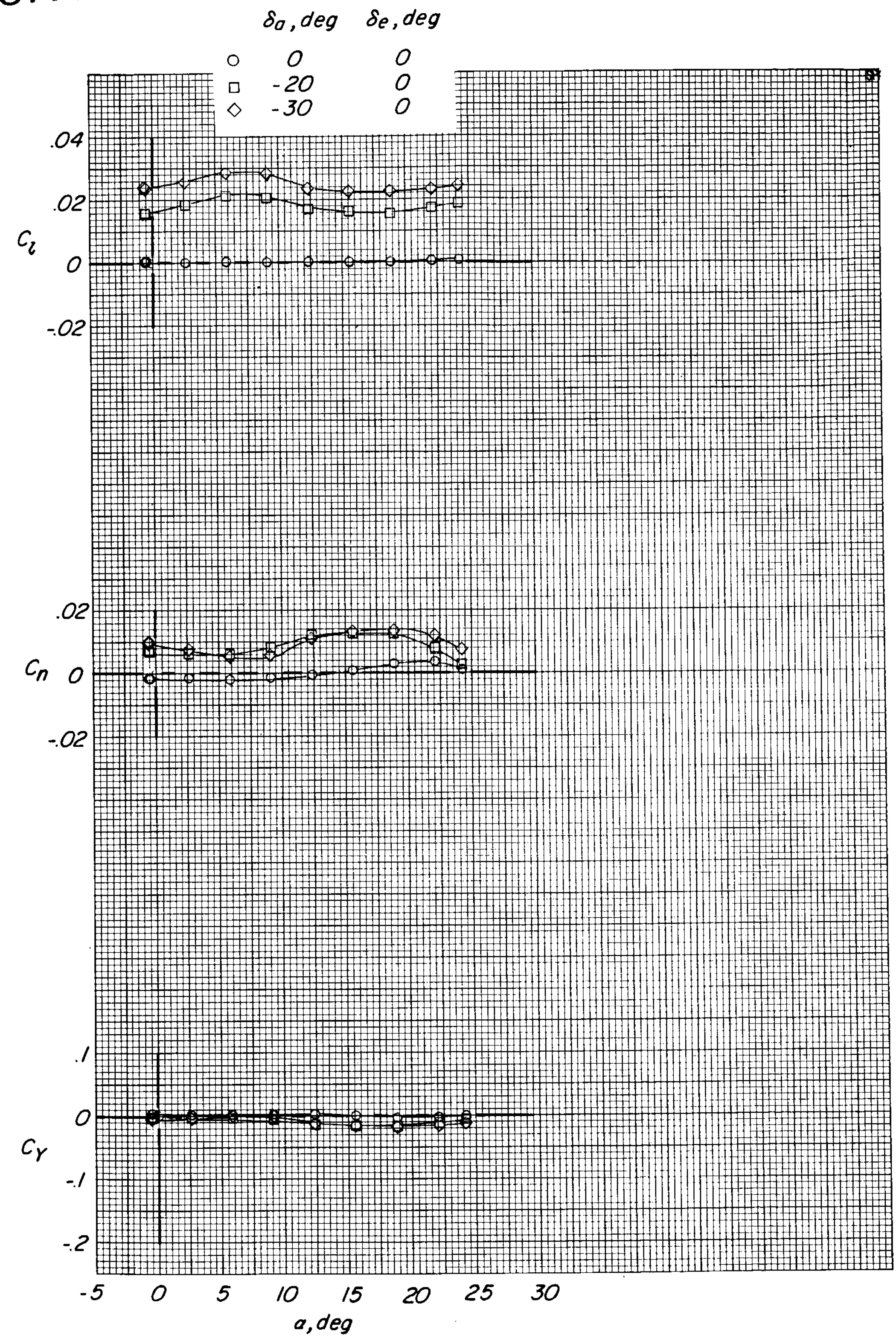

(c) M = 1.10.

Figure 8.- Continued.

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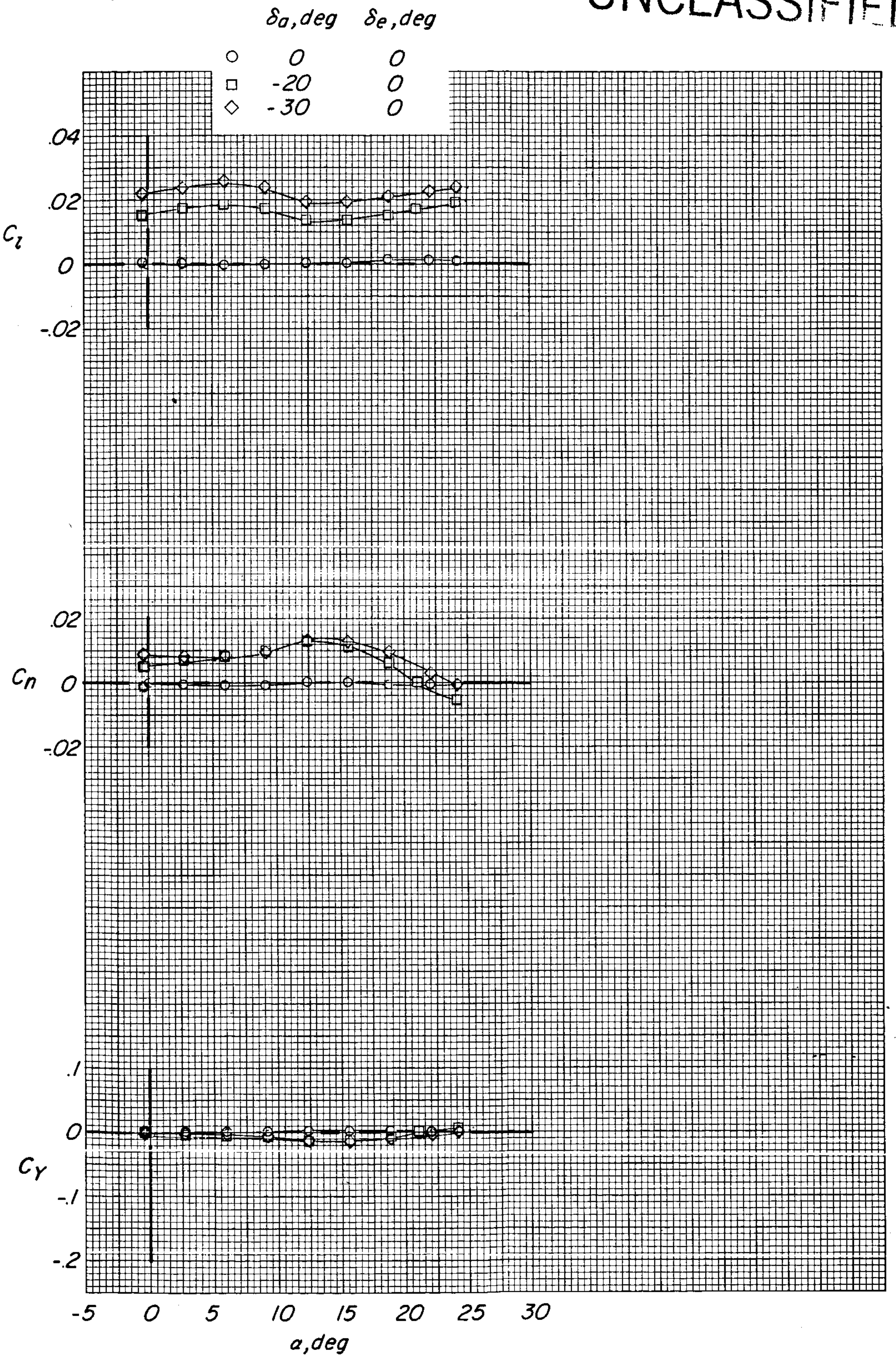

(d) M = 1.20.

Figure 8.- Concluded.

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